

# Biomass and nutritional stock of litter in crop-livestock-forest integration system in Brazilian Cerrado

## *Biomasa y stock nutricional de la hojarasca en el sistema de integración cultivo-ganadería-bosque en el Cerrado brasileño*

Luanna Elis-Guimarães<sup>1</sup>, Ana Carolina Freitas Xavier<sup>2</sup>, Fernanda Gomes Ferreira<sup>3</sup>, Paulo Vitor Divino Xavier de Freitas<sup>4</sup>, Márcio Junior Pereira<sup>5</sup>, Deborah Rodrigues de Souza Santos<sup>6</sup>, Francine Neves Calil<sup>1</sup>, Carlos de Melo e Silva-Neto<sup>7\*</sup>

<sup>1</sup> Universidade Federal de Goiás, Escola de Agronomia, Goiânia, Goiás, Brasil.

<sup>2</sup> Data scientist, McCoy & Partners.

<sup>3</sup> Dot Digital Group, Florianópolis, Santa Catarina, Brasil.

<sup>4</sup> Universidade Estadual de Goiás, Programa de Pós-graduação em Produção Animal e Forragicultura, Goiás, Brasil.

<sup>5</sup> Universidade Estadual de Goiás, Anápolis, Goiás, Brasil.

<sup>6</sup> Universidade de São Paulo, Escola Superior de Agricultura Luiz de Queiroz, Departamento de Ciências Florestais, Piracicaba, São Paulo, Brasil.

<sup>7</sup> Instituto Federal de Goiás, Goiânia, Goiás e Universidade Estadual de Goiás, Ipameri, Goiás, Brasil.

Reception date: 01-20-2025

Acceptance date: 03-31-2025

Publication date: 20-08-2025

\*Correspondence: Carlos de Melo e Silva-Neto. carloskoa@gmail.com

## Abstract

The litter comprises the bed of debris that accumulates on the soil of forest ecosystems. Several biotic and abiotic factors influence the production of *serapilheira*, however, little is known about the contribution of the biomass of *serapilheira* to the nutritional stock only in consortium plantations. The objective of this study was to identify the accumulated litter biomass production and its nutrient contents from intercropping in a crop-livestock-forest integration system (CLFS) of three years of age. Litter accumulated between rows and between plants was collected in the dry and rainy periods. For all the samples, the dry mass and nutritional content were determined. The total average litter biomass production was 17.9 Mg ha<sup>-1</sup>. However, there was a difference among the seasons, and the greatest accumulation occurred during the dry season, as explained by the water stress of the given period. On the other hand, the nutrients did not present any difference between the periods or sites collected. The highest accumulated biomass was obtained in the dry season, and the leaves were the most representative fraction. The contribution of macronutrient storage to the litter followed in the following order: Ca>N>Mg>K>P>S. In micronutrients, it followed: Fe>Mn>B>Zn>Cu. Thus, the stock of litter is of great importance for nutrient cycling in crop-livestock-forest integration system in Brazilian *Cerrado*.

**Keywords:** Agrosilvipastoral. Essential nutrients. Organic matter. Production. Soil. Sustainability.

## Resumen

*La hojarasca comprende el lecho de escombros que se acumula en el suelo de los ecosistemas forestales. Varios factores bióticos y abióticos influyen en la producción de hojarasca, sin embargo, poco se sabe sobre una contribución de biomasa de serapilheira para el suministro nutricional solo en plantas consorciadas. El objetivo de este estudio fue identificar la producción de biomasa de hojarasca acumulada y su contenido de nutrientes a partir de cultivos intercalados en un sistema de integración cultivo-ganadería-bosque (CLFS) de tres años de edad. La hojarasca acumulada entre*

hileras y entre plantas se recolectó en los periodos seco y lluvioso. Para todas las muestras se determinó la masa seca y el contenido nutricional. La producción promedio total de biomasa de hojarasca fue de 17,9 Mg ha<sup>-1</sup>. Sin embargo, hubo diferencia entre las estaciones, y la mayor acumulación ocurrió durante la estación seca, como se explica por el estrés hídrico del periodo dado. Por otro lado, los nutrientes no presentaron diferencia entre los periodos o sitios de colecta. La mayor biomasa acumulada se obtuvo en la época poco lluviosa, siendo las hojas la fracción más representativa. La contribución del almacenamiento de macronutrientes a la hojarasca siguió el siguiente orden: Ca>N>Mg>K>P>S. En micronutrientes fue: Fe>Mn>B>Zn>Cu. Por lo tanto, la reserva de hojarasca es de gran importancia para el ciclo de nutrientes en el sistema de integración cultivo-ganado-bosque en el Cerrado brasileño.

**Palabras clave:** Agrosilvopastoral. Nutrientes esenciales. Materia orgánica. Producción. Suelo. Sustentabilidad.

## Introduction

The litter comprises the bed of debris that accumulates on the soil of forest ecosystems. It is the agglomerate of organic matter on the soil surface that is no longer bound to the original plant and is already at some stage of decomposition (Golley, 1983). The litter represents a respectable correlation in the organic cycle of production-decomposition, being essential for the function of the ecosystem. On the surface of soils and vegetal remnants of a forest (in addition to the seeds of distinct species), there are still nutrients, organic matter, and microorganisms that fundamental for the regeneration of the fertility and the biological activity of these soils (Rodrigues et al., 2010).

Several biotic and abiotic factors influence litter production, such as: temperature, altitude, latitude, precipitation, vegetation type, successional stage, luminosity, relief, deciduousness, water availability, and edaphic characteristics (Calassa et al., 2023). The conservation of the litter in contact with the soil in the forest makes sure that it is reutilized in the ecosystem nutrient cycle (Kleinpaul et al., 2005). By decomposing the litter and releasing the constituent minerals for later reabsorption by the roots of the plants, the relations of the forest-soil-microfauna are improved, in addition to the mutual relations between soil, plants, and microorganisms (Calassa et al., 2023; Velozo et al., 2022).

Nutrition evaluation of a vegetative system is conducted through several methods, however, the correct sampling is of paramount importance for the success of nutritional studies. Nitrogen can be transferred from *Eucalyptus* spp. through litter decomposition (leaves, thin branches, reproductive materials and roots, including root exudates) and subsequent release (Forrester et al., 2006). As the leaves, branches, and roots are being added to the litter and become involved in the action of decomposition, there is release of nutrients to the soil and, therefore, become available to plants (Godinho et al., 2014).

Besides the limitations of these methods, it is difficult to make correct diagnoses, which can be influenced

by several causes such as: sampling time, type of plant tissue, difficulty analyzing factors that interfere with the availability and absorption of essential and non-essential chemical elements, weather, soil management, action of soil microbiota, and cultural and silvicultural management (Bellote and Silva, 2005). The nutrient cycling process is related to the maintenance of the *Eucalyptus* system productive capacity, in which the biomass accumulated on the soil represents a relevant source of nutrients (Santos et al., 2014).

It is understood that knowledge of these dynamics provides support to the planning of forestry management, mainly, with respect to fertilization (Costa et al., 2010; Schumacer et al., 2013; Santos et al., 2014). However, little is known about the contribution of litter biomass to the nutritional stock of the soil in intercropped plantations. The objective of this study was to identify the accumulated biomass production of litter, its contents, and nutrient stocks for an intercropped plantation system in a crop-livestock-forest integration system (CLFS) in two seasons (dry and rainy).

## Materials and Methods

The study was performed from October 2013 to April 2015 in the city of *Cachoeira Dourada*, *Goiás*, Brazil (18°29'30"S, 49°28'30" W), being in the south of the state of *Goiás*. The municipality is at an altitude of 479 meters. According to the Köppen and Geiger classification, the climate is considered the Aw-tropical climate with dry winter season (Alvares et al., 2013). The average annual precipitation varies between 1 200 and 1 500 millimeters, while the majority occurs between the months of October and April. The rainfall distribution is concentrated in the month of January, having an average of 287 mm, and June is the driest month, have an average of 11 mm. The average annual temperature is 18 °C to 22 °C (Alvares et al., 2013).

The CLFS system was implemented in February 2012 in an area of 9.45 ha of degraded pasture located at the *Boa Vereda* farm. The cultivated forest species was *Eucalyptus urograndis* (*E. urophylla* S. T.

Blake × *E. grandis* W. Hill) in combination with the *brachiaria* forage species (*Urochloa brizantha* (Stapf) Webster.). The predominant soil in the study area is the Red Latosol, having a sandy texture and high levels of aluminum and acidity (Gonçalves *et al.*, 2018). The design of the system is formed by blocks of four rows of *E. urograndis* (3×3 m)+22 m, totaling eight blocks of trees. In the first year of cultivation of the system, soil preparation was carried out with sorting in the planting rows, liming, chemical and plant fertilization, and planting of eucalyptus and soybean (*Glycine max* L.). Soybean planting was carried out between eucalyptus trees (22 meters). After 20 days of eucalyptus planting, NPK (08-30-10 – Yara, Brazil) fertilization at 150g/plant, and at the end of the rainy season, fertilization with Boric Acid (Borax®, Brazil) (10g/plant) and Super Simples (Yara®, Brazil) (150g/ plant). In the second year during the harvest period (between November and March), corn (*Zea mays* L.) was planted among the eucalyptus trees, in the *Santa Fé* system. The fertilization carried out in the *Santa Fé* used 200 kg ha<sup>-1</sup> of Urea (Yara®, Brazil), being 100 kg ha<sup>-1</sup> of urea and 100 kg ha<sup>-1</sup> of mono-ammonium phosphate (MAP) (Yara®, Brazil). After the growth of *Eucalyptus* trees, cattle were introduced into the integration system in the third year.

The accumulated litter collections were carried out in two periods: the dry season in September 2014 and the rainy season in February 2015. Samples were collected in six rows. In each row, 10 samples were collected between plants (Treatment 1) and 10 samples between the eucalyptus rows (Treatment 2). A metal template of 0.0625 m<sup>2</sup> (0.25 m×0.25 m) was used for sample collection. All material that accumulated on the soil (leaves, branches/bark, and miscellaneous) was litter in different degrees of decomposition. A total of 120 samples were collected per period, which were stored in Kraft paper bags, identified, and sent to the laboratory (Laboratory of Forest Ecology of Federal University of Goiás) to obtain the dry mass according to the methodology described by Lima *et al.* (2015) and Lemos-Junior *et al.* (2016).

Subsequently, litter components were manually separated for determination of leaf, branch/bark, miscellaneous, and total biomass percentages in Mg ha<sup>-1</sup>. The estimate per unit area (hectare) was performed by extrapolating the dry mass, based on the designated area (0.0625 m<sup>2</sup>). The deposited litter was separated into three fractions: (a) Branches: part of the litter consisting only of branches and bark; (b) Leaves: fraction of litter consisting of dry leaves and/or decomposed; (c) Miscellaneous: reproductive material, fruits, grass, and other plant material which could not be identified (Godinho *et al.*, 2014).

After obtaining the dry mass and subsequently separating the material (leaves, branches, and miscellaneous), the ten litter samples from each treatment (between plants and between eucalyptus rows) were transformed into composite samples. For each row, two composite samples were obtained, one being between plants and another between rows. In each composite sample, there were separate fractions of leaves, branches, and miscellaneous. Thus, 12 samples composed of leaves, 12 of branches, and 12 of miscellaneous were obtained for the six rows, totaling 36 composite samples analyzed in each period-dry and rainy, totaling 12 repetitions for each compartment at each station. Finally, 72 samples corresponding to the two periods were analyzed. All composite samples were milled in a Wiley-type mill (Marconi MA680) and passed through 1.0 mm (20 mesh).

Subsequently, the material was sent for chemical analysis (Laboratory Solocria LTDA), as well as determination of macronutrients and micronutrients in vegetal tissue following the methodology recommended by Tedesco *et al.* (1995) and Miyazawa *et al.* (1999). Nitrogen was determined by sulphuric digestion; phosphorus, potassium, calcium, magnesium, sulfur, manganese and zinc by nitroperchloric digestion, with sulfur and phosphorus being read by flame emission spectrophotometry and calcium and magnesium by reading by atomic absorption spectrophotometry.

For statistical analysis of the data, a 95 % significance analysis was performed comparing the litter biomass between the rainy and dry periods. To verify the components of the litter in relation to the total biomass between the areas (between plants and between rows) and the climatic stations, a principal component analysis (PCA) was performed using a covariance matrix (Silva-Neto *et al.*, 2022). For analysis of the nutritional content, a variance analysis (Veloza *et al.*, 2022) was performed comparing each element (nutrients) between the site (between plants and between rows) and station (dry and rainy) at 95 % significance.

## Results

### Accumulated biomass of litter

The average total litter biomass production accumulated on the soil was estimated at 17.9 Mg ha<sup>-1</sup>. The production of total woody biomass (bark+branches) differed from the dry period to the rainy season with the following results: 2.11 Mg ha<sup>-1</sup> in the dry period, and 1.36 Mg ha<sup>-1</sup> in the rainy season. The total biomass of the miscellaneous was 1.37 Mg ha<sup>-1</sup> in dry

and 0.35 Mg ha<sup>-1</sup> in the rainy season, thus not being very representative. The relative distribution of the above-ground litter components with their total mean in percent followed the following decreasing order: leaves (70 %)>branches/bark (19 %)>miscellaneous (9 %) (Table 1).

Figure 1 shows the biomass for each component in the different times collected, in addition to its total production. In the rainy season, only the leaf component, both between plants and between rows, had greater representation compared to the other components, but it did not present significant differences between them. On the contrary, the dry season samples in which the leaf component obtained a difference between plants and between rows also stood out in comparison to other components analyzed in the same collection season.

At the same time, it could be observed in the same Figure 1 that in both the rainy season and dry season, the branch/bark component between plants obtained greater biomass than the one collected between rows. The miscellaneous' result was different, as one can notice a greater biomass of the component between rows in both periods studied. This can occur due to foraging, weeds, among other components, which are more present between the rows of the block. In the general comparison, the total biomass of the components was higher in the dry season, both between plants and between rows (Figure 1).

It is possible to see that in the dry season the component variations were higher than in the rainy season. Therefore, this verifies that the highest values of the litter production were associated with the dry period, in fact, corroborating with the results of the previous

Table 1. Accumulated litter biomass in Mg ha<sup>-1</sup> and in percentage proportion (%) for each studied period (dry or rainy), in a crop-livestock-forest integration system (CLFS) in the municipality of *Cachoeira Dourada, Goiás, Brazil*.

Component	Total production (Mg ha <sup>-1</sup> )	Proportion (%)
Leaves (Dry)	5.92	62.98
Branches/Bark (Dry)	2.11	22.44
Miscellaneous (Dry)	1.37	14.58
Total during dry season	9.40	100.00
Leaves (Rain)	6.35	78.79
Branches/Bark (Rain)	1.36	16.87
Miscellaneous (Rain)	0.35	4.35
Total during rainy season	8.06	100.00
Total general	17.46	100.00

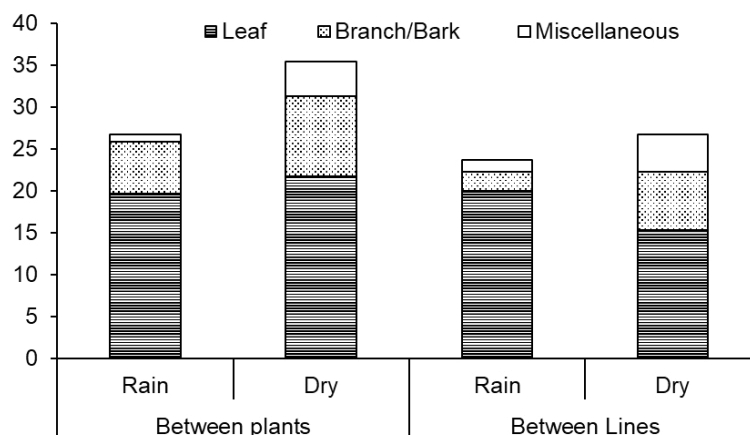


Figure 1. Biomass from different compartments of litter in g m<sup>2</sup> collected in two periods (dry and rainy) in a crop-livestock-forest integration system (CLFS).

figure (Figure 1). The evaluated seasons (drought and rainfall) influenced the differences between the components of accumulated litter biomass.

### Nutritional content and stock in the accumulated litter

The nutritional composition of the litter proved to be different between each component. This is confirmed in Figure 2, which shows the principal component analysis (PCA acronym in English) for macronutrients and micronutrients. The PCA of the accumulated litter nutrients collected in the CLFS system showed that there was no difference between eucalyptus rows of blocks nor between the plants, in relation to the nutrients found in the litter biomass, both presenting similar amounts and nutrients (macro and micro). Between the seasons, there were variations of some nutrients, such as calcium (Ca) and potassium (K). The dry season litter presented lesser amounts of these elements, and the leaf component presented greater variation between the seasons.

The leaf was the component with the highest amount of nutrients, being comprised of elements like nitrogen (N), potassium (K), calcium (Ca), boron (B), magnesium (Mg), manganese (Mn), and sulfur (S). The miscellaneous portion was the leaf-like component and contained the greatest amount of the following nutrients: phosphorus (P), zinc (Zn), iron (Fe), and copper (Cu). In general, the branches/bark component had a lower amount of nutrients.

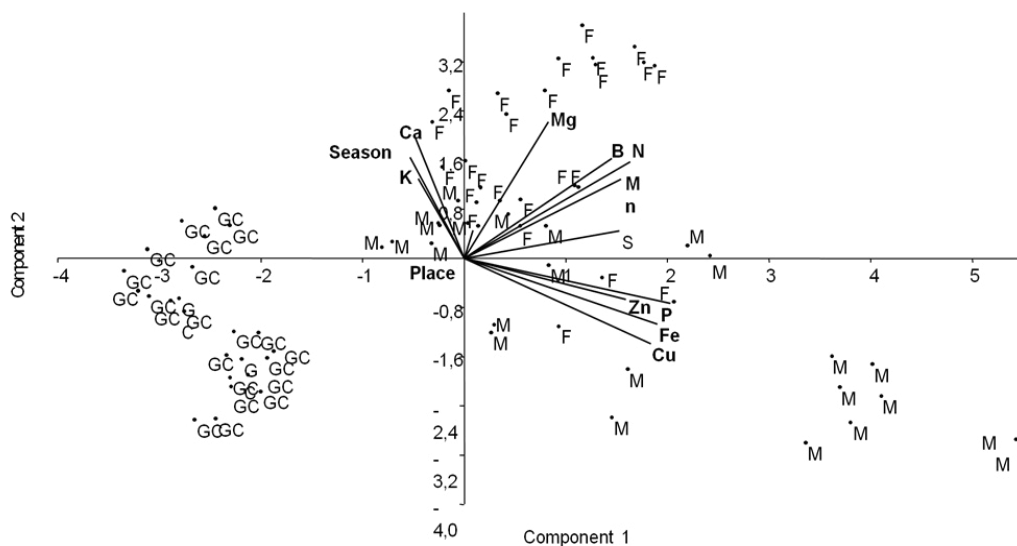
As for the macronutrient content in accumulated litter biomass, the nutrient with the lowest content in

comparison with the other elements was sulfur (S), and calcium (Ca) was the element with the highest content. This was the nutrient that accumulated most prominently in the leaf portion for the biomass collected during the rain period. From the analysis of the micronutrients content in the leaf collected during the dry season, iron (Fe) presented the highest content of all elements considered. In contrast, the lowest content observed was the copper (Cu) in the branch/bark component collected during the rainfall (Table 2).

According to Table 3, it was possible to observe the variations in the nutritional stock present in the sampled litter. Thus, it was possible to observe that the leaf component values were the highest for all macronutrients. As for example, the nutritional stock was 126.43 kg ha<sup>-1</sup> for Nitrogen (N), corresponding to 83.4 % of the total obtained.

In general, the macronutrient stock followed the order leaf>branch/bark>miscellaneous, except for N and P, where the order was changed to leaf>miscellaneous>branch. The overall storage magnitude of the macronutrients followed the order: Ca>N>Mg>K>P>S (Table 4). In the leaf, the order of stock of the macronutrients was: 177.89(Ca)>126.43(N)>35.14(Mg)>30.13(K)>8.81(P)>7.53(S). In the branch/bark component, the macronutrient concentration was: 39.34(Ca)>11.81(N)>8.32(K)>6.67(Mg)>1.36(P)>1.31(S). In the miscellaneous component, the macronutrient stock was: 15.20(N)>12.28(Ca)>4.54(K)>4.18(Mg)>2.03(P)>1.10(S).

The results showed that phosphorus (P) and sulfur (S) were present in the same order in all evaluated



N = 43.32 %; P = 27.18 %; K = 10.80 %\*; Ca = 6.24 %; Mg = 3.82 %; S = 3.43 %; B = 1.71 %; Cu = 1.32 %; Fe = 1.18 %; Mn = 0.70 %; Zn: 0.26 %. \*The last nutrient in the variance components with statistical significance of 95 %.

Figure 2. Principal component analysis of macronutrients of different litter components (leaf, branches/bark, and miscellaneous) for different sites (between plants and between rows) and different climatic seasons.

**Table 2.** Mean nutritional contents of litter components collected during dry and rainy periods according to macronutrients and micronutrients analyzed from the crop-livestock-forest integration system at the Boa Vereda farm in the municipality of Cachoeira Dourada, Goiás, Brazil.

Time	Sample	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		g kg <sup>-1</sup>						mg kg <sup>-1</sup>				
Rainy	Leaf	11.97	0.72	3.33	16.18	2.97	0.71	27.04	22.07	10179.16	359.91	25.11
	Branch-Bark	3.23	0.39	3.66	11.97	2.22	0.31	17.99	9.72	8080.10	95.95	19.12
	Miscellaneous	9.24	0.88	3.66	6.99	2.74	0.55	28.16	25.75	12043.10	264.55	29.90
Dry	Leaf	8.65	0.72	1.59	12.81	2.76	0.51	29.71	43.50	20102.50	698.22	37.46
	Branch-Bark	3.57	0.40	1.14	10.71	1.62	0.45	17.16	10.80	3107.68	119.38	12.87
	Miscellaneous	8.44	1.48	1.62	7.28	2.12	0.72	22.44	30.38	13621.00	451.06	30.88

\*g kg<sup>-1</sup> = Grams per kilogram; mg kg<sup>-1</sup> = Milligrams per kilogram.

**Table 3.** Macronutrient stock of the accumulated litter total and for each evaluated component (leaf, branch/bark, and miscellaneous) in crop-livestock-forest integration system at Fazenda Boa Vereda in the municipality of Cachoeira Dourada, GO.

Sample	N	P	K	Ca	Mg	S
	kg ha <sup>-1</sup>					
Leaf	126.43 (83.4 %)	8.81 (72.21 %)	30.13 (70.08 %)	177.89 (77.51 %)	35.14 (76.40 %)	7.53 (75.83 %)
Branch/Bark	11.81 (7.69 %)	1.36 (11.14 %)	8.32 (19.35 %)	39.34 (17.14 %)	6.67 (14.50 %)	1.31 (13.1 %)
Miscellaneous	15.20 (9.90 %)	2.03 (16.63 %)	4.54 (10.56 %)	12.28 (5.35 %)	4.18 (9.08 %)	1.10 (11.07 %)
Total Litter	153.44 (100 %)	12.20 (100 %)	42.99 (100 %)	229.50 (100 %)	45.99 (100 %)	9.93 (100 %)

\*Kg ha<sup>-1</sup> = Kilograms per hectare.

**Table 4.** Micronutrient stock of the accumulated litter total and for each evaluated component (leaf, branch/bark, and miscellaneous) in crop-livestock-forest integration system at Fazenda Boa Vereda in the municipality of Cachoeira Dourada, Goiás, Brazil.

Sample	B	Cu	Fe	Mn	Zn
	kg ha <sup>-1</sup>				
Leaf	0.47 (81.03 %)	0.28 (65.12 %)	136.87 (73.73 %)	7.67 (85.12 %)	0.32 (65.30 %)
Branches/Bark	0.06 (10.34 %)	0.05 (11.62 %)	13.21 (7.12 %)	0.67 (7.04 %)	0.06 (12.24 %)
Miscellaneous	0.05 (8.62 %)	0.09 (20.93 %)	35.55 (19.15 %)	0.67 (7.04 %)	0.11 (22.45 %)
Total Litter	0.58 (100 %)	0.43 (100 %)	185.62 (100 %)	9.01 (100 %)	0.49 (100 %)

\*Kg ha<sup>-1</sup> = Kilograms per hectare.

components. On the other hand, calcium (Ca) and nitrogen were present in the same order in leaf and branch/bark components. In the branch/bark components, potassium (K) and magnesium (Mg) were present in the same order.

Regarding the micronutrient stock in the evaluated components, the order followed leaf>miscellaneous>branch/bark. The exception to this was B, for which the order was changed to leaf>branch>miscellaneous.

The storage magnitude of micronutrients followed the order: Fe>Mn>B>Zn>Cu. The data in **Table 4**, corresponding to the percentage of micronutrient accumulation, revealed that the leaf component represented the largest stock. It is exemplified in the element boron (B), being 81 % of the total result of the nutritional stock at 0.58 kg ha<sup>-1</sup>.

It was observed that the micronutrients are in the following order of accumulation: Fe>Mn>B>Zn>Cu,

being present in both the leaf and branch/bark components. Only the miscellaneous component had a different sequence in the concentrations of micro-nutrients, following this order: Fe>Mn>Zn>Cu>B. The element of greatest accumulation in the evaluation of the components was Iron (Fe), presenting 185.62 kg ha<sup>-1</sup>.

## Discussion

Observing the totals of each component for each period, the following results were obtained in the dry period: leaves 5.92 Mg ha<sup>-1</sup>, branches/bark 2.11 Mg ha<sup>-1</sup> and miscellaneous 1.37 Mg ha<sup>-1</sup>. In the rainy period, the leaves were: 6.35 Mg ha<sup>-1</sup>, branches/bark 1.36 Mg ha<sup>-1</sup>, and miscellaneous 0.35 Mg ha<sup>-1</sup>. The accumulated biomass results obtained corroborated approximately with the results of (Viera *et al.*, 2012), who obtained 18.5 Mg ha<sup>-1</sup> when evaluating a settlement of *E. urograndis* in the region of the sierra in the southeast of Rio Grande do Sul.

With the results of this study, it was possible to observe that the total leaf biomass production in the two periods also corresponded to the highest accumulation, while the total biomass was noticeably higher for the dry season. This production is explained as being a response mechanism to water stress to reduce the loss of water by transpiration, and therefore there was such a loss of leaves of the trees during the dry season (Alves *et al.*, 2010). In comparing this study with the other works of (Godinho *et al.*, 2014), it can be observed that seasonality was a decisive factor in the production of litter. This is because of the characteristics of specific plants, including exotic ones, leaf loss, and, as a result, the highest rates of litter deposition being associated to the dry period.

The greater deposition in the dry season is also explained by (Moreira and Silva, 2004), which clarify the reason for greater litter production occurring in the dry season. This is a consequence of the decrease in precipitation causing a water stress on the forest ecosystem that uses the fall of leaves to mitigate its water consumption. However, the values of total biomass obtained in the rainy season were lower. This may be the result of factors pertinent to the decomposition rate and mainly due to the influence of temperature and precipitation (Caldeira *et al.*, 2008). A variation was observed in the material referring to the seasons in which they were collected ( $F(3, 213)=15.16$ ;  $p=0.000$ ).

A relevant fact that other authors noted was that the high precipitation rates occurring in the rainier months like February and March may have caused the

litter that was accumulated on the ground (Caldeira *et al.*, 2007; Wink *et al.*, 2022). The plantation being on a slope helps to also clarify the relative decrease of the biomass between the periods. Was determined that the composition of species varies in the amount of litter on the soil, as well as the influence of the successional stage, the amplitude of the forest cover, the age, the time of collection, the type of forest, and the location (Caldeira *et al.*, 2008). Also reports several additional factors, such as edaphoclimatic conditions, understory, crown ratio, silvicultural management (Godinho *et al.*, 2014). The author also reports percentage of decomposition and both natural disturbances, such as insect/pest attack and fire, or artificial disturbances, such as removal of litter and crops, occurring in the forest or in the settlement. All this may also influence the accumulation of litter.

The initial stages of *Eucalyptus* cultivation in integrated system, like the present work at three years of age, already contribute accumulation of litter in the soil, and consequently, the nutritional stock. Every forest ecosystem has a great dynamic in the biomass flow, occurring as the forest develops. There is a gradual reduction in the plant biomass, observed mainly in the initial phase of growth of forest plantations and availability of mineral nutrients in the plant (Ramos *et al.*, 2019; Velozo *et al.*, 2022).

In the literature, it is reported that the leaves are the structures where there is greater metabolic activity and, therefore, there is a tendency for majority of the nutrients to concentrate in these structures of the plant (Viera *et al.*, 2012; Taiz and Zeiger, 2009). The nitrogen content (N) is much higher in the leaves, as compared to the other components. This since this element participates in most reactions of metabolism of compounds, such as amino acids, proteins, amines, amides, vitamins, among others, as observed through photosynthesis that occurs in leaves (Coelho *et al.*, 2021).

This lower sulfur content (S) in all components can be explained that stated that sulfur and nitrogen are constituents of proteins, acting in the same regions, and consequently, with the same functions. The difference is that sulfur is not easily transported to newer leaves of most species. The branch/bark component presented higher Ca content because this element has a certain immobility in the phloem of the plant. This is explained by its high concentration in the shell fraction, as well as the fact that the element is a structural component, being part of the middle lamella of cell membrane (Brun *et al.*, 2010). State that thinning does not affect the order of macronutrient deposition, even after 13 years of application of silvicultural

treatments (Kolm and Poggiani, 2003). The comparison may be confounded by the methodological difference used in the studies and therefore, causes changes in the percentage and functionality of bark and branches (Corrêa et al., 2013). Differences between concentration and nutrient content among species, compartments, and age were verified by Velozo et al. (2022).

The miscellaneous content collected during both the rainfall and the dry season was the component with the lowest Ca content, presenting no differences between the collected periods (dry and rainy). This is shown in **Table 2**. The dynamics of the litter in the forest system is important for maintaining productivity, even in soils with low availability of nutrients (Calil et al., 2013). The concentrations of the macronutrients of this work are in the following order leaf>branch>miscellaneous. This order was also found by Corrêa et al. (2013), which evaluated the nutrient cycling in planting of *Eucalyptus dunni* Maiden. In the works with *Eucalyptus* sp. of Viera et al. (2012), was measured the magnitude of storage of the different elements in the total biomass and presented the following decreasing order of accumulation for the macronutrients and micronutrients, respectively: Ca>N>K>Mg>P>S and Mn>Fe>B>Zn>Cu.

This shows a greater similarity in the macronutrients, differentiating only the order of Mg>K. Regarding the micronutrient results, there was no similarity in the order of any element. From the work with a silvipastoral system, Calil et al. (2016) and Velozo et al. (2022) obtained results with similarity to the present micronutrients, being: Fe>Mn>Zn>B>Cu. The only difference was that Cu>B in the present work. These differences in the orders between the works are very small in the total values and can be explained by differences in the collection time of each experiment, which influences the nutrient cycling dynamics.

The litter is fundamental for the self-sustainability of forest ecosystems, representing the beginning of the first stage of nutrient transfer to the system. It is in this phase that much of the nutrients absorbed by the vegetation returns to the soil when it falls from the plant (Caldeira et al., 2008). An essential role played by the accumulated litter is the increase of the cation exchange capacity (CEC) of the soil (Garay et al., 2004). In addition, the accumulated material allows for the existence of a great variety of niches for the mesofauna, microflora, and microorganisms of the soil, as well as being a source of colloids for the soil (Wink et al., 2022).

Another important factor is the microclimate, being observed in the crop-livestock-forest integration systems (Wink et al., 2022). This favors moisture retention and the recycling of nutrients, resulting in the best qualities for the productivity of any system. In fact, shade allows greater retention of water in the soil, resulting in greater decomposition of organic matter and, consequently, nitrogen cycling (Santos et al., 2014; Guimarães et al., 2016).

It is also visible in the few but well-made socioeconomic studies, that productivity and profitability reach 10 to 30 % of annual crop yields and are almost three times higher for beef cattle than for traditional production systems. In the case of more complex systems that involve the use of arboreal components, there is an increase in animal welfare and a decrease in greenhouse gases (Porfírio-Da Silva et al., 2010). As in livestock, annual crops also show high productivity. Based on the obtained data in the study it is possible to conclude that trees did not affect maize yield in a CLFS, considering that only 60 % of the area was used for agriculture, maize yield was higher than when it is planted in total area (Silva et al., 2020).

There is greater efficiency in the use of soil nutrients by crops in crop-livestock integration systems, as compared to single crops (Vilela et al., 2011). This results in significant savings on fertilizers at the end and, therefore, the reduction of production costs. However, these profits are not always easy to obtain in the short term. In order to increase the productivity of the components (agricultural, animal, and forest), future studies should focus on the density and diversification of trees, forage, animal environment, and nutrient cycling, both for this region of the Cerrado of Goiás and for the other regions of the country.

## Conclusions

The accumulated biomass of total litter is greater in the dry season. The leaf component has greater representation in the total biomass of the litter for both seasons measured. There were differences in the accumulated litter between the collection sites for branch/bark and miscellaneous components, during both the dry and rainy periods. For the leaf component, there was only a difference for the dry period.

The magnitude of biomass accumulation in the litter fractions follows this order: Leaf >Branch/Bark>Miscellaneous. The general storage order of macronutrients in the litter followed as: Ca>N>Mg>K>P>S. In micronutrients, the order was: Fe>Mn >B>Zn>Cu.

Among the climatic seasons, there were variations of some nutrients, such as calcium (Ca) and potassium (K), and the dry season presented litter with smaller amounts of these elements.

Quantification of the macro and micronutrients will allow for improved management of the system cover fertilization. This is because the litter biomass accumulated in the environment is part of the natural nutrient cycling, which reduces the need for higher levels of commercial fertilizers.

## Acknowledgements

FAPEG (Fundação de Amparo à Pesquisa do Estado de Goiás) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPQ) to productivity grants (author Carlos de Melo e Silva Neto). We thank EMBRAPA researcher Abílio Rodrigues Pacheco for his research partnership.

## Cited Literature

- Alvares C. A.; Stape J. L.; Sentelhas P. C.; De Moraes, J. L. G.; Sparovek, G. 2013. Köppen's climate classification map for Brazil (en Inglés). *Meteorologische Zeitschrift*, 22(6): 711-728.
- Alves, L. S., Holanda, A. C.; Wanderley, J. A. C.; Sousa, J. S.; Almeida, P. G. 2010. Regeneração natural em uma área de caatinga situada no município de Pombal-PB-Brasil (en Português). *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, 5(2): 152-168.
- Bellote, A. F. J.; Silva, H. D. 2005. Técnicas de amostragem e avaliações nutricionais em plantios de *Eucalyptus* spp (en Português). In: Gonçalves J.; L. M. e V. Benedetti (Edits.). *Nutrição e fertilização florestal*. Instituto de Pesquisas e Estudos Florestais (IPEF). Piracicaba, Brasil. pp105-133.
- Brun, E. J.; Brun, F.G. K.; Corrêa, R.S.; Vaccaro, S.; Schumacher, M. V. 2010. Dinâmica de micronutrientes na biomassa florestal em estágios sucessionais de Floresta Estacional Decidual, RS, Brasil (en Português). *Scientia Forestalis*, 38(86): 307-318.
- Calassa, C. H. J.; Ferreira, J. L.; Pereira, M. J.; Calil F. N.; Silva-Neto, C. De M. E. 2023. Aporte e decomposição de serapilheira em área em restauração no Cerrado (en Português). *Ecologia e Nutrição Florestal*, 11, 01. DOI: 10.5902/2316980X84358.
- Caldeira, M. V. W.; Vitorino, M. D.; Schaadt, S. S.; Moraes, E.; Balbinot, R. 2008. Quantificação de serapilheira e de nutrientes em uma Floresta Ombrófila Densa (en Português). *Semina: Ciências Agrárias*, 29(1), 53-68. <https://www.redalyc.org/pdf/4457/445744087006.pdf>. Consulted: 10/nov/2022.
- Caldeira, M. V. W.; Marques, R.; Soares, R. V.; Balbinot, R. 2007. Quantificação de serapilheira e de nutrientes- Floresta Ombrófila Mista Montana-Paraná (en Português). *Revista Acadêmica*, 5(2): 101-116.
- Calil, F. N.; Viera, M.; Schumacher, M. V.; Lopes, V. G. Witschoreck, R. 2013. Biomassa e nutrientes em sistema agrossilvicultural no extremo sul do Brasil (en Português). *Ecologia e Nutrição Florestal*, 12: 80-88. Doi: 10.13086/2316-980x.v01n02a04.
- Calil, F. N.; Lima, N. L.; Silva, R. T.; Moraes, M.D. A.; Barbosa, P.V. G.; Lima, P.A. F.; Brandão, D. C.; Silva-Neto, C. de M. e, Carvalho, H. C. S.; Nascimento, A. R. 2016. Biomass and nutrition stock of grassland and accumulated litter in a silvopastoral system with Cerrado species (en Inglés). *African Journal of Agricultural Research*, 11: 3701-3709. DOI: 10.5897/AJAR2016.11369.
- Coelho, M. C. B.; Lima, E. N.; Erpen, M. L.; Barilli, J.; Varavallo, M. A.; Silva, M. V. C.; Giongo, M. 2021. Aporte de nutrientes em diferentes compartimentos de Eucalipto no sul do Tocantins (en Português). *Journal of Biotechnology and Biodiversity*, 9(1): 28-39.
- Corrêa, R. S.; Schumacher, M. V.; Momolli, D. R. 2013. Deposição de serapilheira e macronutrientes em povoamento de *Eucalyptus dunnii* Maiden sobre pastagem natural degradada no Bioma Pampa (en Português). *Scientia Forestalis*, 41(97): 65-74
- Costa, C. C. A.; Camacho, R. G. V.; Macedo, I. D.; Silva, P. C. M. 2010. Análise comparativa da produção de serapilheira em fragmentos arbóreos e arbustivos em área de caatinga na Flona de Açú-RN (en Português). *Revista Árvore*, 2(34): 259-265.
- Forrester, D. I.; Bauhus, J.; Cowie, A. L.; Vanclay, J. K. 2006. Mixed-species plantations of *Eucalyptus* with nitrogen-fixing trees: a review (en Inglés). *Forest Ecology and Management*, 233: 211-230.
- Garay, I.; Pellens, R.; Kindel, A.; Barros, E.; Franco, A. A. 2004. Evaluation of soil conditions in fast-growing plantations of *Eucalyptus grandis* and *Acacia mangium* in Brazil: a contribution to the study of sustainable land use (en Inglés). *Applied Soil Ecology*, 27(2): 177-187.
- Godinho, T. O.; Caldeira, M.V. W.; Rocha, J.H. T.; Caliman, J. P.; Trazzi, P. A. 2014. Quantificação de biomassa e nutrientes na serapilheira acumulada em trecho de Floresta Estacional Semidecidual Submontana-ES (en Português). *Cerne*, 20(1):11-20.
- Golley, F. B. 1983. Tropical rain forest ecosystems - Structure and function (en Inglés). Elsevier scientific Publ.; *Ecosystems of the world*. 14A. Amsterdam, Netherlands. 381.
- Guimarães, L. E.; Silva-Neto, C. M.; Calil, F. N. 2016. Densidade de Fluxo de Fótons (DFF) em um sistema de Integração Lavoura-Pecuária-Floresta (ILPF) (en Português). *Revista Ecologia e Nutrição Florestal - ENFLO*, 4(1): 1-9. DOI: 10.5902/2316980X21143.
- Kleinpaul, I. S.; Schumacher, M. V.; Brun, E. J.; Brun, F. G. K.; Kleinpaul, J. J. 2005. Suficiência amostral para coletas de serapilheira acumulada sobre o solo em *Pinus elliottii* Engelm, *Eucalyptus* sp. e floresta estacional decidual (en Português). *Revista Árvore*, 29(6): 965-972.

19. Kolm, L.; Poggiani, F. 2003. Ciclagem de nutrientes em povoamentos de *Eucalyptus grandis* submetidos à prática de desbastes progressivos (em Português). *Scientia Forestalis*, 63: 79-93.
20. Lemos-Junior, J. E. M.; Silva-Neto, C. M.; Souza, K. R.; Guimarães, L. E.; Oliveira, F. D.; Gonçalves, R. A.; Calil, F. N. 2016. Volumetric models for *Eucalyptus grandis* x *urophylla* in a crop-livestock-forest integration (CLFI) system in the Brazilian cerrado (em Inglês). *African Journal of Agricultural Research*, 11(15): 1336-1343.
21. Lima, N. L.; Silva-Neto, C. M.; Calil, F. N.; Souza, K. R.; Moraes D. C. 2015. Acúmulo de serapilheira em quatro tipos de vegetação no Estado de Goiás (em Português). *Enciclopédia Biosfera*, 11(22): 39-46.
22. Ministério de Minas e Energia e Empresa de Pesquisa Energética (MME/EPE). 2006. Avaliação Ambiental Integrada (AAI) dos aproveitamentos hidroelétricos da bacia hidrográfica do Rio Paranaíba (em Português). Engenharia SA-PROJETEC - EPE. Brasília, Distrito Federal, Brazil. 80. <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-248/topico-291/AAI%20Paranaiba%20-%20P5%20Relatorio%20Final%20e%20Sumario%20-%20Sumario%20Executivo.zip>. Consulted: 11/ene/2018.
23. Miyazawa, M.; Pavan, M.; Muraoka, T.; Carmo, C.; Mello, W. 1999. Análises químicas de tecido vegetal (em Português). In: Silva, F. C. (Org.). Manual de análises químicas de solos, plantas e fertilizantes (em Português). Embrapa Informação Tecnológica, Brasília D.F.; Rio de Janeiro, Brazil, pp171-223.
24. Moreira, P. R.; Silva, O. A. 2004. Produção de serapilheira em área reflorestada (em Português). *Revista Árvore*, 28(1):49-59.
25. Ramos, T. V.; Ferreira, J. L. S.; Silva-Neto, C. M.; Calil, F. N.; Silva, I. C.; Carrijo, U. M. 2019. Components of Tree Biomass in an Integrated Crop-Livestock-Forest System (em Inglês). *Journal of Experimental Agriculture International*, 34(5): 1-12. DOI: 10.9734/jeai/2019/v34i530185.
26. Rodrigues, B. D.; Martins, S. V.; Leite, H. G. 2010. Avaliação do potencial da transposição da serapilheira e do banco de sementes do solo para restauração florestal em áreas degradadas (em Português). *Revista Árvore*, 34(1): 65-73.
27. Santos, H. G.; dos Jacomine, P. K. T.; dos Anjos, L. H. C.; de Oliveira, V.A.; Lumberras, J. F.; Coelho, M. R.; Almeida, J. A. de; Araujo filho, J. C. de; Oliveira, J. B. de; Cunha, T. J. F. 2018. Sistema Brasileiro de Classificação de Solos (em Português). Embrapa. Brasília, Distrito Federal, Brazil. 355 p. <https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1094003/2/SiBCS2018ISBN9788570358004.pdf>. Consulted: 29/sep/2023.
28. Santos, J. C. dos, Schumacher, M. V.; Witschoreck, R.; Araújo, E. F.; Lopes V. G. 2014. Nutrientes na serapilheira acumulada em um povoamento de *Eucalyptus saligna* Smith em São Gabriel, RS (em Português). *Ecologia e Nutrição Florestal*, 2(1): 1-8. DOI: 10.5902/2316980X15045.
29. Silva, V. P. da, Medrado, M. J. S.; Nicodemo, M. L. F.; Dereti, R. M. 2010. Arborização de pastagens com espécies florestais madeiras: implantação e manejo (em Português). Embrapa Pecuária Sudeste. Colombo, Paraná, Brazil. 48. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/132912/1/2014-reimp-Cartilha-Arborizacao-2014.pdf>. Consulted: 10/nov/2022.
30. Schumacher, M. V.; Corrêa, R. S.; Viera, M.; Araújo, E. F. 2013. Produção e decomposição de serapilheira em um povoamento de *Eucalyptus urophylla* x *Eucalyptus globulus maidenii* (em Português). *Cerne*, 19(3): 501-508.
31. Silva, F. F. C.; Ferreira, J. L. S.; Ramos, T. V.; Calil, F. N. 2020. Maize yield in an integrated crop-livestock-forestry system in south Goiás, Brazil (em Inglês). *Revista Ceres*, 67(3): 176-180.
32. Silva-Neto, C. de M.; Freitas, P. V. D. X. de, Pina, I. J.; Santos, B. C. dos, Rodrigues, N. C. A.; Silveira, A. L. R.; Gonzaga, G. F.; Calil, F. N. 2022. Nutrient composition of Brazilian savanna trees and their potential for animal feed (em Inglês). *Australian Journal of Crop Science*, 16, 415. DOI: 10.21475/ajcs.22.16.03.p3564.
33. Taiz, L.; Zeiger, E. 2009. Fisiologia vegetal (em Português). Artmed editora. Porto Alegre, Brazil. 379.
34. Tedesco, M. J.; Gianello, C.; Bissani, C. A.; Bohnen, H.; Volkweiss, S. J. 1995. Análise de solo, plantas e outros materiais (em Português). Editora da Universidade Federal do Rio Grande do Sul-UFRGS. Porto Alegre, Brazil. 174. [https://rolas.cnpt.embrapa.br/arquivos/manual\\_rolas.pdf](https://rolas.cnpt.embrapa.br/arquivos/manual_rolas.pdf). Consulted: 10/nov/2022.
35. Velozo, A. P.; Pacheco, A. R.; Calil, F. N.; Silva-Neto, C. M. 2022. Nutrients in litter of four eucalyptus clones under an Integrated Crop-Livestock-Forest System (CLFS) (em Inglês). *Revista Ecologia e Nutrição Florestal-ENFLO*, 10:e01. DOI: 10.5902/2316980X68328.
36. Viera, M.; Bonacina, D. M.; Schumacher, M. V.; Calil, F. N.; Caldeira, M. V. W.; Watzlawick, L. F. 2012. Biomassa e nutrientes em povoamento de *Eucalyptus urograndis* na Serra do Sudeste-RS (em Português). *Semina: Ciências Agrárias*, 33(1): 2481-2490.
37. Vilela, L.; Junior, G. B. M.; Macedo, M.C. M.; Marchão, R. L.; Júnior, R. G.; Pulrolnik, K.; Maciel, G. A. 2011. Sistemas de integração lavoura-pecuária na região do Cerrado (em Português). *Pesquisa Agropecuária Brasileira*, 46(10): 1127-1138. DOI:
38. Wink, C.; Souza, F. D.; Tonini, H.; Morales, M. M. 2022. Influência de fatores climáticos e espaciais na produção de serapilheira do eucalipto em sistemas integrados (em Português). *Advances in Forestry Science*, 9(2): 1751-1760.